End-stage extension of the knee and its influence on tibial tuberosity-trochlear groove distance (TTTG) in asymptomatic volunteers

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Abstract: PURPOSE: Increased tibial tuberosity-trochlear groove distance (TTTG) is one potential correcting parameter in patients suffering from lateral patellar instability. It was hypothesized that end-stage extension of the knee might influence the TTTG distance on MR images. METHODS: Transverse T1-weighted MR images of the knee were acquired at full extension, 15° and 30° flexion of the knee in 30 asymptomatic volunteers. MRI parameters: slice thickness: 3 mm, matrix: 256 × 384, FOV: 150 × 150 mm. Two observers independently measured the TTTG at all positions. RESULTS: Mean TTTG for observer 1 was 15.1 ± 3.2 mm at full extension, 10.0 ± 3.5 mm at 15° flexion and 8.1 ± 3.4 mm at 30° flexion. Mean TTTG for observer 2: 14.8 ± 3.3 mm at full extension, 9.4 ± 3.0 mm at 15° flexion, 8.6 ± 3.4 mm at 30° flexion. Mean values were significantly different ($p < 0.001$) between full extension and 15° as well as 30° flexion for both observers. Mean values were significantly different ($p < 0.001$) between 15° and 30° for observer 1, but not for observer 2 (n.s.). Interobserver agreement was very good (intraclass correlation coefficient: 0.87-0.88; $p < 0.001$). CONCLUSIONS: The TTTG increases significantly at the end-stage extension of the knee. Therefore, the comparability of published TTTG values measured on radiographs, CT and MRI at various flexion/extension angles of the knee are limited. LEVEL OF EVIDENCE: Development of diagnostic criteria in a consecutive series of patients and a universally applied 'gold' standard, Level II.

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Conclusions The TTTG increases significantly at the end-stage extension of the knee. Therefore, the comparability of published TTTG values measured on radiographs, CT and MRI at various flexion/extension angles of the knee are limited.
Level of evidence Development of diagnostic criteria in a consecutive series of patients and a universally applied 'gold' standard, Level II.

Keywords TTTG · TAGT · Screw-home mechanism · MRI · Patellar instability

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Introduction

The position of the tibial tuberosity related to the trochlear groove is important for the inferolateral force vector of the patella [7]. Although patellar instability is multifactorial [6], an increased tibial tuberosity-trochlear groove distance (TTTG) is one of the possible factors contributing to lateral patellar instability [3, 6]. Various normal values for the TTTG are provided in the literature for indication and planning of medialization osteotomy of the tibial tuberosity [20]. However, these TTTG values were measured with different modalities and at different flexion angles of the knee [6, 8, 16, 18–20]. While the original TTTG data were measured on radiographs of the knee at 30° flexion [8], currently, cross-section imaging such as CT-scans or MRI is mostly used.

The so-called screw-home mechanism refers to an outward rotation of the tibia when the knee reaches full extension [17]. It was speculated that lateralization of the tibial tuberosity relative to the trochlear groove due to end-stage extension of the knee might increases the TTTG distance [21]. It was hypothesized that various angles of knee flexion might influence the TTTG distance on MR images. These data are not available in the English peer-reviewed literature. Thus, the purpose of this prospective

study was to evaluate and compare the TTTG on magnetic resonance imaging at full extension, 15° and 30° flexion of the knee on transverse T1-weighted MR images of the knee in 30 asymptomatic volunteers.

Materials and methods

The institutional review board approved this prospective study. All volunteers signed informed consent before the imaging examination. Inclusion criteria were individuals between 18 and 37 years of age without any symptoms or previous history of pain, instability or surgery of the examined knee. Exclusion criteria were contraindications for MRI, pregnancy, rheumatic disorders affecting the joints, obvious genu varum or genu valgum. Thirty asymptomatic volunteers were included in the present analysis. Volunteers were classified into age groups with a balanced female to male ratio and right knee to left knee ratio. Ten volunteers of both genders were between 18–24 years, 25–31 years and 32–37 years old, respectively. The mean age and standard deviation of the volunteers were 28.7 ± 5.3 years.

Imaging protocol

All individuals were examined in one of two 1.5 T MR units (Magnetom Espree and Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany) or a 3.0 T MR unit (Magnetom Verio, Siemens Medical Solutions, Erlangen, Germany), depending on scanner availability. Transverse spin-echo T1-weighted MR images of the knee covering the entire trochlea of the femur and tibial tuberosity were acquired at full extension, 15° and 30° flexion of the knee in all 30 asymptomatic volunteers using a flexible coil and a goniometer. The quadriceps muscle was relaxed at all knee positions. Sagittal MR localizer images served to ensure accuracy of each knee position. The specific imaging parameters for the Verio 3.0 Tesla MR scanner were as follows: repetition time msec [TR]/echo time msec [TE], 502/23.0; field of view, 150 × 150 mm; matrix, 256 × 384; slice thickness, 3 mm; sections per slab, 30; imaging time, 98 s. The protocol varied slightly for the other scanners.

Determination of TTTG on MRI

A fellowship trained musculoskeletal radiologist (TJD, 2 years experience in musculoskeletal radiology) and a resident in orthopaedic surgery (MB, 4th year resident) measured the TTTG at all three positions on T1-weighted transverse MR images. The resident in orthopaedic surgery was trained specifically by the musculoskeletal radiologist for the purpose of this study. Both observers measured the TTTG individually to ensure independent measurements. The most distal MRI slice with full cartilage coverage of the trochlear groove and the MR image with the patellar tendon proximate to its insertion on the tibial tuberosity were selected for evaluation of the TTTG. The TTTG was determined as the distance between the midpoint of the distal patellar tendon and a reference line through the deepest point of the trochlear groove at right angles to the tangent along the posterior femoral condyles (Fig. 1) [16, 18]. The method allowed measurements with an accuracy of 0.4 mm, and data were obtained likewise. The two observers took all measurements using electronic calipers on a picture archiving and communication system (PACS) workstation (AGFA Impax 6.4.0.4551, Agfa HealthCare, Mortsel, Belgium).

Statistical analysis

Mean values and standard deviations of the TTTG measurements were calculated for all three knee positions by both observers. Mean values were compared for differences between full extension and the two flexed positions, as well as between 15° and 30° of knee flexion using the Student's t test. A p value less than 0.05 was considered significant. The intraclass correlation coefficient (ICC) was used to assess interobserver agreement. A computer software package (SPSS, version 17.0, SPSS) was used for all statistical calculations.

Results

The mean TTTG for observer 1 was 15.1 ± 3.2 mm at full extension, 10.0 ± 3.5 mm at 15° flexion and 8.1 ± 3.4 mm at 30° flexion (Table 1). The corresponding TTTG values for observer 2 were 14.8 ± 3.3 mm at full extension, 9.4 ± 3.0 mm at 15° flexion and 8.6 ± 3.4 mm at 30° flexion. The mean TTTG values were significantly different ($p < 0.001$) comparing full extension with the two different positions of knee flexion (15° and 30°) for both observers (Table 2; Fig. 1). The mean TTTG values were also significantly different ($p < 0.001$) between 15° and 30° for observer 1, but not for observer 2 (n.s.). Interobserver agreement was very good at all three positions with an ICC between 0.87 and 0.88; $p < 0.001$ (Table 3).

Discussion

The most important finding of the present study was that the TTTG distance increases significantly at the end-stage

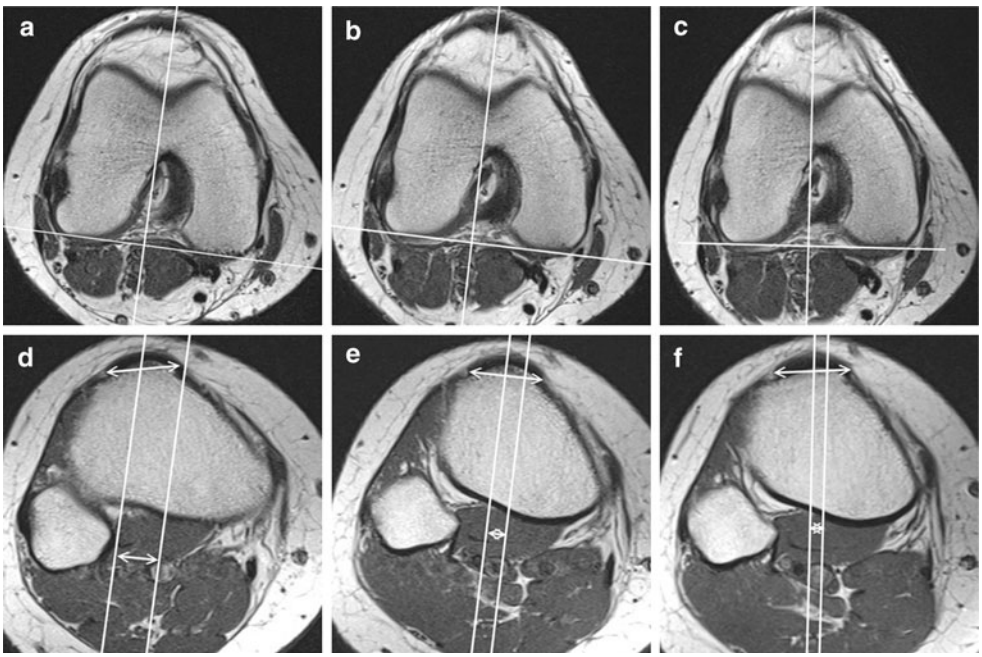

Fig. 1 24-year-old female with a TTTG distance of 11.8 mm on transversal T1-weighted MR images (TR/TE: 502/23.0) at full extension (**a**, **d**), a TTTG distance of 5.9 mm at 15° flexion (**b**, **e**) and a TTTG distance of 3.9 mm at 30° flexion (**c**, **f**) of the right knee. MR images at the most distal slice with full cartilage coverage of the trochlear groove (**a**–**c**) and MR images with the patellar tendon proximate to its insertion (**d**–**f**). The TTTG was determined as the distance (posterior double arrows on MR images **d**–**f**) between the midpoint of the distal patellar tendon (anterior *double arrows* on MR images **d**–**f**) and a reference line through the deepest point of the trochlear groove at right angles to the tangent along the posterior femoral condyles

Table 1 Values for TTTG distance at full extension, 15° and 30° flexion of the knee on transversal T1-weighted MR images in 30 asymptomatic volunteers

	Full extension		15° Flexion		30° Flexion	
	Observer 1	Observer 2	Observer 1	Observer 2	Observer 1	Observer 2
Mean ± standard deviation (mm)	15.1 ± 3.2	14.8 ± 3.3	10.0 ± 3.5	9.4 ± 3.0	8.1 ± 3.4	8.6 ± 3.4

TTTG tibial tuberosity-trochlear groove distance

Table 2 Differences for TTTG distance at full extension, 15° and 30° flexion of the knee on transversal T1-weighted MR images in 30 asymptomatic volunteers

	Full extension versus 15° flexion		Full extension versus 30° flexion		15° versus 30° flexion	
	Observer 1	Observer 2	Observer 1	Observer 2	Observer 1	Observer 2
Mean ± standard deviation (mm)	5.1 ± 2.3	5.4 ± 2.4	7.0 ± 3.4	6.1 ± 3.1	1.9 ± 2.6	0.7 ± 2.4
p values	<0.001	<0.001	<0.001	<0.001	0.00039	n.s.

TTTG tibial tuberosity-trochlear groove distance, *n.s.* not significant

Table 3 Intraclass correlation coefficient (ICC) for interobserver agreement of TTTG values

	ICC observer 1 & observer 2	*p* value
Full extension	0.879	<0.001
Flexion 15°	0.871	<0.001
Flexion 30°	0.868	<0.001

TTTG tibial tuberosity-trochlear groove distance

extension of the knee in asymptomatic volunteers with a very good interobserver agreement at full extension, 15° and 30° flexion of the knee in asymptomatic volunteers. Measurement of TTTG distance is a routine procedure to quantify lateralization of the tibial tubercle, or a medialized trochlear groove in trochlear dysplasia [18]. A lateralized tibial tubercle is a relevant anatomic risk factor for patellar instability and lateral patellar dislocations, respectively

[3, 6]. Trochlear dysplasia and patella alta are additional contributing factors to an unstable patella [6, 7].

The TTTG can be measured with various imaging modalities such as conventional radiographs, computed tomography and magnetic resonance imaging. Goutallier et al. [8] were the first to describe a technique to determine the TTTG distance on conventional radiographs with 30° of knee flexion in 1978. Later, the TTTG distance was measured with CT-scans without considering the influence that the screw-home mechanism may have on this measurement. The varying TTTG distances reported in the literature have been determined at different flexion and extension degrees of the knee. Most studies measured the TTTG distance at full extension [2, 16, 22]. The TTTG was also evaluated at 15° of knee flexion on CT images in 60 knees of asymptomatic volunteers and at 20° of knee flexion on CT images in 60 patients with anterior knee pain as well as in 10 asymptomatic controls [1, 10].

Two studies compared the position of the tibial tubercle in full knee extension and at 30° of flexion on computed tomography images [13, 14]. One of these studies compared the tibial tubercle position in knees with patellar instability to 'control' knees without patellar instability [13]. An angle was measured using a line drawn between the tibial tuberosity and the central point of the transepicondylar line and a line drawn between the tibial tuberosity and the highest point of the lateral femoral condyle. The authors found that in full extension and at 30° flexion, the tibial tubercle was in a significantly more lateral position in the unstable compared to the control knees and that at 30° flexion, the tibial tubercle in the unstable knees rotated internally. A further study compared the position of the tibial tubercle at full extension and at 30° flexion in knees with patellofemoral arthritis [14]. In contrast to the above mentioned study, the tibial tubercle was in almost the same position at full extension in normal and patellofemoral arthritic knees. However, it was significantly more lateral at 30° of flexion in patellofemoral arthritic knees compared to the control group. Unfortunately, neither study measured the tibial tuberosity distance from the trochlear groove for their assessment (i.e. the TTTG distance) [13, 14].

Because of the increasing frequency of the use of MRI for the assessment of knee pathologies, one study compared CT-scans with MRI for the assessment of TTTG distance in patients with patellofemoral instability or anterior patellofemoral pain syndrome [18]. The authors measured a mean TTTG of 15.3 ± 4.6 mm on CT-scans and 13.5 ± 4.1 mm on MR images. Unfortunately, there is no information about the degree of flexion of the assessed knees. However, the study found excellent interrater, intermethods and interperiod quantitative reliability [18]. The TTTG distance was assessed as one of the gold standard measurements in the evaluation of patellar instability [5].

In a recent review article on MR Imaging of patellar instability, Diederichs et al. [7] suggest a TTTG distance of 15–20 mm as borderline and a value more than 20 mm as nearly always associated with patellar instability. However, they did not mention the flexion and extension degrees of the knee in conjunction with the reference values.

Pandit et al. [16] assessed MRI and found it to be a reliable method of TTTG measurement. However, the authors also stated that the literature supports a high degree of variability in reporting in normal values of TTTG. In support of the results of Pandit et al. [16] and Schoettle et al. [18], this current study has also shown a very good interobserver measurement agreement at all three positions of the knee.

One may suggest that the literature appears to be contradictory concerning TTTG distances with a high interrater, intermethods reliability for CT and MRI and high interperiod quantitative reliability in several studies, but in contrast, a high degree of variability in reporting TTTG in several other studies. However, previous studies did not consider the flexion or extension degree of the knee in TTTG distance evaluation. This study provides an explanation for the high degree of variability in reporting TTTG in the literature.

One may speculate that the screw-home mechanism [17] explains the increasing TTTG distance in the end-stage extension of asymptomatic knees. However, the present study is not able to prove this relationship. The screw-home mechanism seems to be more pronounced in healthy knee motion. Decreased or even reversed screw-home motion has been described in osteoarthritic knees and after total knee arthroplasty [4, 9, 12, 15]. Therefore, the influence of knee end-stage extension on TTTG distance could be evaluated in circumstances with reduced screw-home motion to provide more information on the role of the screw-home mechanism as a possible explanation of the present results.

Which TTTG value is clinically the most relevant is not answered, however, as that was not the purpose of this study. Both 15 and 20 mm are suggested in the literature as threshold values of the TTTG distance for indication and planning of medialization osteotomy of the tibial tuberosity [2, 6, 11]. Thus, the flexion, extension or full extension angles of the knee should be clearly annotated in MRI or CT reports with TTTG measurements. Moreover, the degree of knee flexion during TTTG measurement should be taken into account for the indication and planning of medialization osteotomy of the tibial tuberosity. MR images in 15° of knee flexion afford a comfortable position to the patient and may minimise motion artefacts.

This study had limitations: The end-stage extension of the knee and its influence on TTTG distance in asymptomatic volunteers were evaluated. The results observed

might not reflect the pathological mechanisms that occur in knees with patellar instability.

Conclusion

The TTTG distance increases significantly in the end-stage extension of the knee. Therefore, the comparability of published TTTG values measured on radiographs, CT and MRI at various flexion/extension angles of the knee is limited.

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